Unit 42: Heat Transfer and Combustion

HNC/HND Mechanical Engineering

THC-4

Chris Rooney

Grading Criteria					
Pass	**Assessed in course work**	**Merit**	**Assessed in course work**	**Distinction**	**Assessed in course work**
1.1	1	M1	1, 2	D1	1
1.2	1	M2	3, 4	D2	2
1.3	1	M3	1, 2, 3 and 4	D3	4
2.1	2				
2.2	2				
2.3	2				
3.1	3				
3.2	3				
3.3	3				
4.1	4				
4.2	4				
4.3	4				

Module Leader(s)	Author(s)	IV Signature
Ashwin Dobariya	Ashwin Dobariya	Owen Latham

PASS grade **must be achieved**:

Outcomes	Learner has demonstrated the ability to:	Source of evidence
Outcome 1 Understand heat transfer rates for composite systems	**LO1.1:** Apply Fourier's law and the Newton rate equation to composite solids and fluid/solid interfaces	Course work 1 Question 1
	LO1.2: Calculate heat transfer rates for combined modes including radiation	Course work 1 Question 2
	LO1.3: Evaluate lagging for optimum performance	Course work 1 Question 3
Outcome 2 Understand heat transfer mechanisms and coefficients	**LO2.1:** Apply dimensional analysis to energy and mass transfer relationships	Course work 2 Question 4
	LO2.2: Evaluate heat transfer mechanisms	Course work 2 Question 5
	LO2.3: Determine heat transfer coefficients using experimental and tabulated data	Course work 2 Question 6
Outcome 3 Be able to evaluate heat transfer equipment.	**LO3.1:** Evaluate various types and layout of recuperators	Course work 3 Question 7
	LO3.2: Estimate heat transfer performance	Course work 3 Question 8
	LO3.3: Specify recuperator type, size and fluids for given applications	Course work 3 Question 9
Outcome 4 Be able to analyse the combustion processes	**LO4.1:** Derive combustion equations	Course work 4 Question 10
	LO4.2: Determine calorific value	Course work 4 Question 11
	LO4.3: Analyse products of combustion	Course work 4 Question 12

MERIT criteria that may be achieved:

Merit Grade Descriptors	Indicative Characteristics	Contextualisation	Source of evidence
M1 Identify and apply strategies to find appropriate solutions	Effective judgements have been made	Evaluate the ability of the material to efficiently transfer heat from the hot gas to the cold gas (max 250 words).	Course work 1 Question 1
		Using heat transfer principles evaluate why the atmosphere gets colder with increasing altitude (max 250 words)	Course work 2 Question 5
M2 Select/design and apply appropriate methods/techniques	The design of methods/techniques has been justified	Re-calculate the length of the pipe for both cases using fouling factor of 0.0006 m^2 ^0C /W and explain the effect of fouling on performance of heat exchanger.	Course work 3 Question 8
		Re-calculate the stoichiometric air to fuel ration if excess air is 30% and explain the effect this would have on the combustion process. Also compare and contrast the results (max 300 words).	Course work 4 Question 10
M3 Present and communicate appropriate findings	The communication is appropriate for familiar and unfamiliar audiences and appropriate media have been used	Throughout the reports, the solutions are coherently presented using technical language appropriately and in a professional manner	All Questions

DISTINCTION criteria that may be achieved:

Distinction Grade Descriptors	Indicative Characteristics	Contextualisation	Source of evidence
D1 Use critical reflection to evaluate own work and justify valid conclusions	Conclusions have been arrived at through synthesis of ideas and have been justified	The use of Argon Gas as an insulator is a modern concept. Discuss the merits of this statement and appropriateness of its application (max 350 words).	Course work 1 Question 3
D2 Take responsibility for managing and organising activities	Substantial activities, projects or investigations have been planned, managed and organised	In the experiment to determine heat transfer coefficients, the methods employed, and errors found between the practice and the theory has been evaluated (max 350 words).	Course work 2 Question 6
D3 Demonstrate convergent/ lateral/ creative thinking	Innovation and creative thought have been applied	Explain the purpose of the Bomb and Boy's CALORIMETER's, highlighting the difference between them and any variance in the results obtained using the values given in Q11 (max 500 words).	Course work 4 Question 11

Course work 4

Course work 4

M3 Requirement for all questions: Throughout the reports, the solutions are coherently presented using technical language appropriately and in a professional manner

Learning Outcomes 4.1

4.1: Derive combustion equations

10 (a) Derive the combustion equation of the following Gaseous fuels.

a. Pentane

C5H12

a = 5   b = 12

CaHb + (a+$\frac{1}{4}$b) O_2 = CO_2 + ($\frac{1}{2}$b) H_2O

C5H12 + (5+12/4) O_2 = 5CO_2 + (12/2) H_2O

Answer = C5CH12 + 8O_2 → 5CO_2 + 6H_2O

b. Cycloheptane

C7H14

a = 7   b = 14

CaHb + (a+$\frac{1}{4}$b) O_2 = CO_2 + ($\frac{1}{2}$b) H_2O

C7H14+ (7+14/4) O_2 = 7CO_2 + (14/2) H_2O

C7H14 + 10.5CO_2 → 7CO_2 + 7 H_2O

Answer = 2C7CH14 + 21O_2 → 14CO_2 + 14H_2O

c. Hexane = C6H14 + 19 O2 → 12 CO2 + 14 H2O.

C6H14

a = 6   b = 14

CaHb + (a+$\frac{1}{4}$b) O_2 = CO_2 + ($\frac{1}{2}$b) H_2O

C6H14 + (6+14/4) O_2 = 6CO_2 + (14/2) H_2O

C6H14 + 9.5 CO_2 → 6CO_2 + 7 H_2O

Answer = 2C6CH14 + 19O_2 → 12CO_2 + 14H_2O

d. Benzenol

C6CH6

a = 6   b = 6

CaHb + (a+$\frac{1}{4}$b) O_2 = CO_2 + ($\frac{1}{2}$b) H_2O

C6H6 + (6+6/4) O_2 = 6CO_2 + (6/2) H_2O

C6H6 + 7.5CO_2 → 6CO_2 + 3 H_2O

Answer = 2C6CH6 + 15O_2 → 12CO_2 + 6H_2O

e. Heptane

C7H16

a = 7 b = 16

$CaHb + (a+\frac{1}{4}b)\ O_2 = CO_2 + (\frac{1}{2}b)\ H_2O$

$C7H16 + (7+16/4)\ O_2 = 7CO_2 + (16/2)\ H_2O$

$C7H16 + 11CO_2 \rightarrow 7CO_2 + 8\ H_2O$

Answer = $C6CH6 + 11O_2 \rightarrow 7CO_2 + 8\ H_2O$

10 (b) A sample of dry anthracite coal has the following composition by mass.

C = 90%; H = 3%; O = 2%; N = 1%; S = 0.5%; ash = 3%.

Calculate:

a. The stoichiometric air to fuel ratio.

Carbon

$C + O_2 \rightarrow CO_2$

12kgC +32kg $\rightarrow$ 44 CO_2

For 1 kg

1kg C + $\frac{32}{12}\ O_2 \rightarrow \frac{44}{12}\ CO_2$

For 0.9kg C +O_2 required $\rightarrow$2.4kg/kg coal $\rightarrow$3.3kg CO_2 product.

Hydrogen

$H_2 + \frac{1}{2}\ O_2 \rightarrow H_2O$

2 kg H_2 + 16 kg $O_2 \rightarrow$ 18 kg H_2O

1 kg H_2 + 8 kg $O_2 \rightarrow$ 9 kg O_2 = 0.03 x 9 kg H_2O

0.03 kg $H_2 + O_2$ required 0.24kg/kg coal $\rightarrow$ steam product 0.27kg/kgcoal

Sulphur

$S + O_2 \rightarrow SO_2$

32 kg s + 32 $O_2 \rightarrow$ 64 SO_2

1 kg s + 1kg $O_2 \rightarrow$ 2 kg SO_2

0.005kgs + O_2 required 0.005kg\kg coal $\rightarrow$ SO_2 produced 0.01kg\kg coal

Results in Table

Constituent	Mass fraction	0_2 Required kj\kg	Product mass kj/kg
C	0.900	2.400	3.30
H	0.030	0.240	0.27
S	0.005	0.005	0.01
O	0.025	-0.025	……
N	0.010	………	0.01
ASH	0.030	……….	……

Total oxygen

C+H+S

= 2.4 + 0.24 + 0.005 = 2.645 kg

Total air = 2.645/0.233% = 11.35kg

The stoichiometric air/fuel ratio = 11.35/1

b. The actual air to fuel ratio, when 20% excess air is supplied.

Formula % excess air

$= \frac{actual\ A\backslash F\ ratio - stoichmetric\ \backslash F\ ratio}{stoichmetric\ A\backslash F\ ratio}$

$11.35 + \frac{20}{100} \times 11.35 = 13.62$

The stoichiometric air/fuel ratio = 13.62/1 (**rich mixture**)

c. The dry and wet gas analysis of the products of combustion by mass and volume, when 20% excess air is supplied.

Composition of air (Gravimetric %)

O_2 = 0.233%

N_2 = 0.767%

N_2 supplied = 0.767 x 13.62 = 10.45 N_2

O_2 supplied = 0.233 x 13.62 = 3.17 0_2

In the products we then have.

N_2 10.45 + 0.01 = 10.46

Product	Product mass (mi)	% of mass (mi/m) %	Mass of moles (mi)	Amount of subs kg/of coal ni =mi/mi	Wet ni/n %	Dry ni/n %
CO_2	3.300	22.81	44	0.0750	15.74	16.25
HO_2	0.270	1.87	18	0.0150	3.15	…..
SO_2	0.010	0.07	64	0.0002	0.04	0.04
O_2	3.17	3.62	32	0.0164	3.44	3.55
N_2	10.46	71.63	28	0.3700	77.63	80.16
total	17.21	= 100	…..	Wet = ni = 0.4766 Dry = ni = 0.4616	= 100	= 100

M2 requirement: Re-calculate the stoichiometric air to fuel ration if excess air is 30% and explain the effect this would have on the combustion process. Also compare and contrast the results (max 300 words).

30%

Formula % excess air

$$= \frac{actual\ A\backslash F\ ratio - stoichmetric\ \backslash F\ ratio}{stoichmetric\ A\backslash F\ ratio}$$

$11.35 + \frac{30}{100}$ x 11.35 = 14.755

The stoichiometric air/fuel ratio = 14.755/1 (stoichiometric) = 15/1 (**optimum mixture**)

20%

Formula % excess air

$$= \frac{actual\ A\backslash F\ ratio - stoichmetric\ \backslash F\ ratio}{stoichmetric\ A\backslash F\ ratio}$$

$11.35 + \frac{20}{100}$ x 11.35 = 13.62 (**rich mixture**)

The stoichiometric air/fuel ratio = 13.62/1 falls short of the perfect ratio.

Compare and Contrast

To have the most efficient combustion in a process the quantities of fuel have to be the perfect ratio with no unused air or fuel.

In theory this type of perfect scenario is known as **stoichiometric combustion**. But in practice and for safety reasons as well as maintenance, extra additional air has to be introduced into the combustion process. This is called excess air. An example would be that of a boiler, if some excess is not added, soot, smoke, unused fuel and carbon monoxide exhaust cause extra unwanted emissions and results in fouling on the surface.

Caution needs to be taken; we need to control the excess air as it will reduce the flames instability and other boiler hazards and defects. Too much excess air will lower the boilers efficiency. So, a balance needs to be found that provides the optimal amount of excess air. Obtaining the ideal combustion will prevent combustion problems that arise with too little excess air. Boilers tend to increase excess air requirements as the firing rate of the boiler decreases; this leads to a lower efficiency at the lower end of the firing range.

Results

The calculations show that 30% excess air added to the combustion process is the correct amount of excess air required to bring the air to fuel ratio to 15/1 which is optimum performance for example a boiler as mentioned above, improving on the initial 20%, excess air which produces a 13/1 ratio known as a (**rich mixture**), this would cause fouling and combustion problems.

Learning Outcome 4.2

4.2: Determine calorific value

11 (a) A bomb calorimeter is used to determine the Higher Calorific Value of an oil sample. The mass of the sample is 1.01 g. The total equivalent mass of water is 1.32kg. The increase in temperature after ignition is 7.8 K. The specific heat of water is 4.186 kJ/kg K. Calculate the higher calorific value of the oil.

H.C.V = $M_W C\Delta T/m_f$ = 1.32 x 4.186 x 7.8/0.00101

= 42672kJ/kg or 42.672 kJ/kg

11 (b) The results of a test with Boy's calorimeter shows that the volume of gas burned at standard conditions is 0.005 m^3, volume of water heated in the same time is 1900g, temperature rise of the water is given as 20.17 K and the specific heat of water is 4.186kJ/kg K. Calculate the higher calorific value of gas.

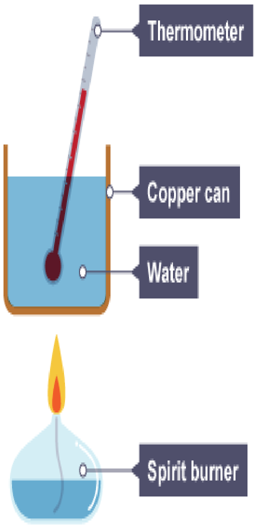
H.C.V = ($M_W C\Delta T$/ Volume of gas.

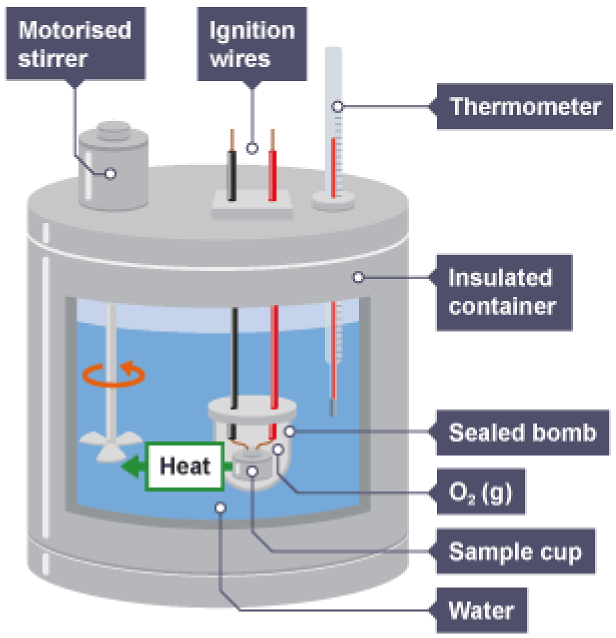
= (1.9 x 4.186 x 20.17)/0.005 = 32084.0156

= 32000kJ/m^3

D3 requirement: Explain the purpose of the Bomb and Boy's CALORIMETER's, highlighting the difference between them and any variance in the results obtained using the values given in Q11 (max 500 words).

The bomb Calorimeter and Apparatus





Is a certain type of constant volume calorimeter that measures the heat of combustion of a particular reaction. Bomb calorimeters must be able to withstand the large pressure within the calorimeter, as the reaction is being measured. Electrical energy is used to ignite the fuel, using a 6V supply it is utilised as the fuel is burning. It will heat up the surrounding air which then expands and escapes through a tube that leads the air out of the calorimeter. When the air escapes through the copper tube it will also heats up the water outside of the tube. The change in temperature of water allows for calculating calorie content of the fuel.

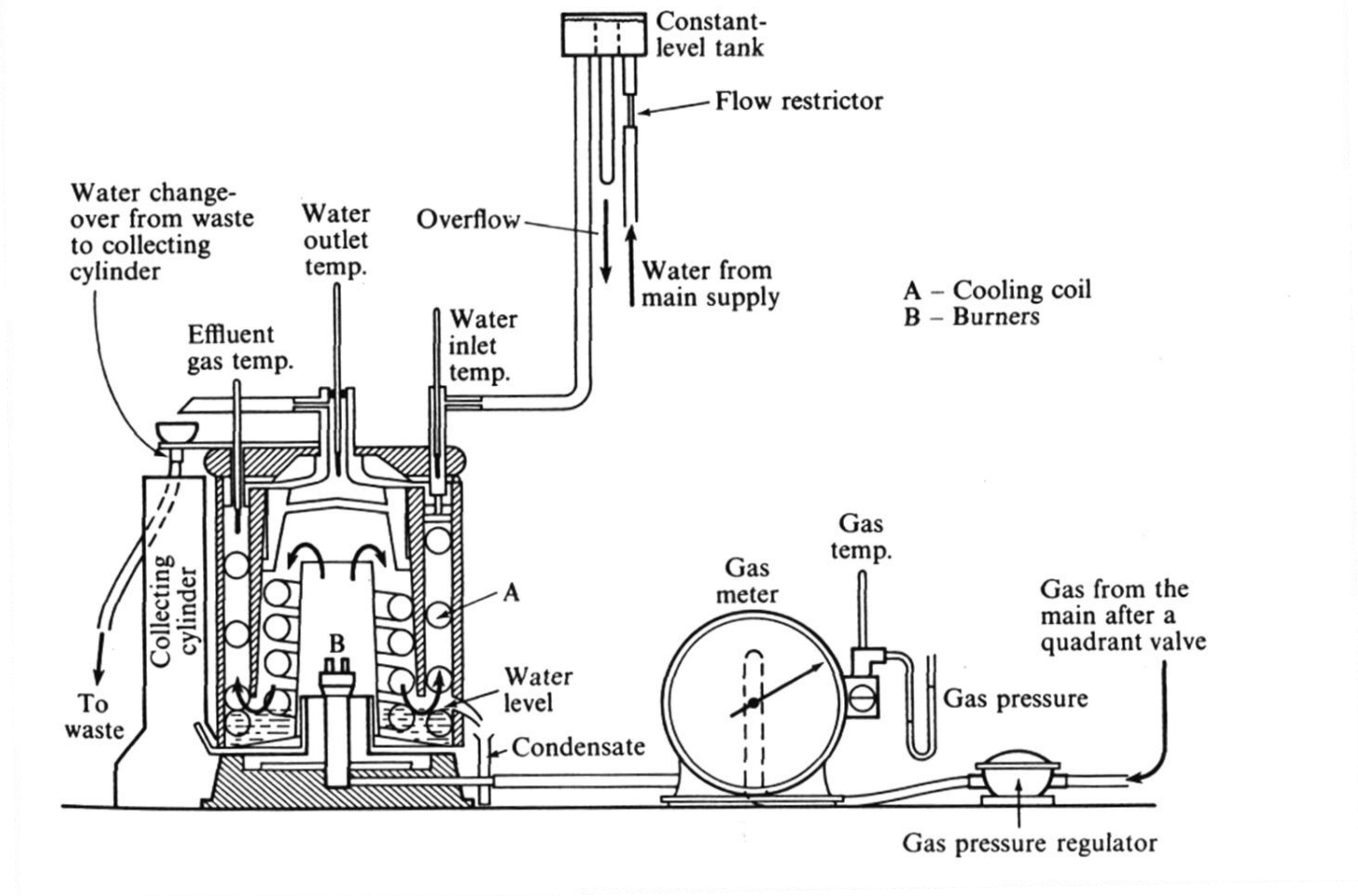
A bomb calorimeter consists of.

- A small cup to contain the sample
- Oxygen
- Stainless steel bomb
- Water
- Stirrer
- Thermometer
- Insulating container
- Ignition circuit connected to the bomb, using a stainless steel for the bomb.

The reaction will occur with no volume change observed.

http://www.bbc.co.uk/education/guides/z8p72hv/revision/3

The Boys Gas Calorimeter



Is designed to make sure that the heat from the burner flows up through the calorimeter container and back down again inside of the container and back up again before finally exhausting. This type of experiment is based on heat transfer methods which involve burning the gaseous fuel for heating the water that flows and circulates in a coiled heat exchanger. This design guarantees maximum heat transfer to the cooling liquid and hence accurate enough for measurement and calculations of calorific values of gas.

The amount of heat liberated when a unit mass of fuel is completely burnt is known as the calorific value. Calorific value is the amount of heat that is produced by the complete combustion of a fuel or any materials. The higher calorific value or higher heating means that the water of combustion is completely condensed and the heat contained in the water vapour is recovered while the lower calorific value or lower heating value means that the products of combustion contains water vapour and is not recovered.

https://www.scribd.com/doc/154609859/The-Boys-Gas-Calorimeter

Compared Results

Bomb Calorimeter

H.C.V = $M_W C\Delta T/m_f$ = 1.32 x 4.186 x 7.8/0.00101

= 42672J/kg or 42.672 MJ/kg

The boys Gas Calorimeter

H.C.V = ($M_W C\Delta T$/ Volume of gas

= (1.9 x 4.186 x 20.17)/0.005 = 32084.0156

= 32000kJ/m^3

Summary

From the results obtained.

- The bomb calorimeter determines the calorific value of solids and non-volatile liquid fuels.
- The boy calorimeter determines the calorific value of gaseous fuels.

Conclusion

Comparisons in results cannot be obtained, as they measure different equations and quantities. Bomb Calorie is measured in joules. The Boy Calorimeter measures in kg, from the results we can see that an oil has been determined by the bomb calorimeter with the results of 42.672MJ/kg according to charted sources. This fluid is known as kerosene, or diesel oil. From the results obtained using the boy calorimeter apparatus, the solid used can also be determined, the results of 32,000KJ/m^3, according to chart information suggest this solid is Coal.

Learning Outcomes 4.3

4.3: Analyse products of combustion

12 The enthalpy of reaction for solid carbon being burned to form carbon monoxide gas is -150 kJ/kmol. The enthalpy of reaction for solid carbon dioxide gas is given as -400 kJ/kmol. What is the enthalpy of reaction when carbon monoxide gas is burned to form carbon dioxide? Write clearly the reaction equations.

$C + O = CO$
$C + O_2 = CO_2$
$CO + \frac{1}{2} O2 = CO_2$

Δh_O -150kJ/kmol

Δh_O - 400KJ/kmol

Δh_O - 400 – (-150) = + 250KJ/kmol

End of course work 4

End of Module Brief

REFERENCES

http://www.bbc.co.uk/education/guides/z8p72hv/revision/3

https://www.scribd.com/doc/154609859/The-Boys-Gas-Calorimeter